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Composite material having a reinforced connecting r gion

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The invention relates to a composite material comprising a fiber composite, a large number of fiber layers embedded in a polymer matrix, some of which preferably have fiber directions which differ from fiber directions of other fiber layers, and a connecting region formed using a reinforcement material with a high embedding strength, with a transitional region being formed between the fiber composite and the connecting region, in which fiber layers abut against the reinforcement material of the connecting region.

Modern fiber composites with a polymer matrix, for example carbon fiber or glass fiber reinforced plastics (CFC or GFC) have high tensile and compressive strength. Fiber layers with fiber directions lying in the tension and compression direction are responsible for the high tensile and compressive strength. It is normal to design a fiber composite with fiber directions lying at 0°, 90° and +/- 45° or the like with respect to the longitudinal direction. For high tensile strength, the proportion of the 0° layers is greater than the respective proportions of the other fiber layers with different fiber directions.

As a rule, it is necessary to connect fiber composite components produced in such a way to other components of the same type or a different type. This is frequently done using bolted joints. The 0°

direction fiber layers which are responsible for high tensile strength and compressive strength have only a very low embedding strength, however. An improved embedding strength can be obtained by an increased proportion of obliquely directed fiber layers (for example +/- 45°, +/- 30° or the like), although this reduces the tensile strength for the same cross section or the same thickness of the fiber composite.

It is thus known for the fiber composite material to be provided with a connecting region, which is formed using a reinforcement material with a high embedding strength. It is known, for example, for a monolithic or else layered titanium material to be connected to the fiber composite, with a connection whose layers are stepped being produced in order to improve the joint between the fiber composite and the reinforcement material. It is thus known for a monolithic metallic connecting region, composed of titanium for example, to be provided on a connecting edge with respectively stepped projections, which are symmetrical to the center plane with respect to the height of the connecting region, and for the fiber layers of the fiber composite to be connected in a corresponding manner. The connection to the fiber composite can be produced via the polymer matrix or via adhesive coatings.

It is furthermore known for the connecting region to be formed with metallic laminate layers whose thickness corresponds to the thickness of the fiber

layers of the fiber composite, so that stepped configuration of the connection is easy to achieve.

It is furthermore known for the composite structure formed by the fiber layers to be separated in the connecting region and for metallic layers to be inserted between the mutually separated fiber layers, in order to increase the embedding strength. Such an arrangement is known for a tube composed of a fiber composite, which has a constant internal diameter in the connecting region, but whose external diameter is enlarged by the inserted metal layers.

A disadvantage of the last-mentioned solution is the necessary asymmetry in the connecting region with respect to the fiber composite, as a result of which weak points are produced with regard to static and dynamic loads. In the other solutions, the connection between the fiber composite and the connecting region is governed exclusively by shear and adhesion forces between the fiber layers and the reinforcement material. Since such connections which are based on shear forces have only a limited tensile strength, the achievable high tensile strength of the fiber composite becomes obsolete as a result of the connecting region that is applied.

The invention is thus based on the problem of designing a composite material of the type mentioned initially such that a high tensile strength can be achieved, including the connecting region, and a high embedding strength can be achieved in the connecting

region.

Ins C2 Against the background of this problem, a composite material of the type mentioned initially is distinguished, according to the invention, in that the connecting region is formed from layers of the reinforcement material and by fiber layers which pass through the transitional region into the connecting region, and in that, in the transitional region between the fiber layers which pass through, fiber layers which do not pass through abut against corresponding layers composed of the reinforcement material.

In the composite material according to the invention, the connecting region is thus formed from fiber layers of the fiber composite which pass through and are combined with layers of the reinforcement material. It is thus possible to ensure a high embedding strength in the connecting region by virtue of the reinforcement material, and a high tensile strength in the transitional region, by virtue of the fiber layers which pass through. Furthermore, the connecting region can advantageously be designed to have the same thickness as the fiber composite, thus making it possible to completely avoid the creation of any asymmetries in the transition from the fiber composite to the connecting region.

It is particularly preferable for the composite material according to the invention for the abutment points between the fiber layers which do not pass through and the layers of the reinforcement material to

be arranged offset in the transitional region. The offset is in this case preferably designed such that starting from the fiber composite in the transitional region, abutment points are initially formed between the reinforcement material and fiber layers (the 90° layer for a tensile load) which contribute at least to the strength of the fiber composite to withstand a main load, for example to withstand tension, and abutment points for fiber layers of increasing importance for the strength follow offset in the direction of the connecting region. If, for example, a high tensile strength is relevant, this means that abutment points for the 90° layers are formed first of all, and that abutment points for, for example, +/- 45° layers then follow, with abutment points between 0° layers and the reinforcement material finally being formed as the last step. In this case, steps may once again be produced within the individual groups as well.

It is particularly expedient for the composite material according to the invention for the fiber layers of the fiber composite to be arranged symmetrically with respect to the center plane of the thickness of the fiber composite and for the abutment points then likewise to lie symmetrically with respect to the center plane of the thickness of the fiber composite, in each case, in the transitional region. This also makes it possible to achieve symmetry with respect to the fiber layers across the thickness of the fiber composite, into the connecting region.

The fiber layers which pass through and the layers composed of the reinforcement material are preferably formed in alternate layers in the connecting region. This maintains the desired symmetry and a high embedding strength is achieved with a high strength, which also remains in the transitional region, to withstand the main load of the fiber composite (in particular tensile strength). The fiber layers and the layers composed of the reinforcement material expediently all have the same layer thickness.

The layer thickness of the fiber layers and of the layers of the preferably metallic (titanium) reinforcement material are preferably between 0.2 and 1 mm.

From what has been said above, it is evident that, expediently, the fiber layers which pass through into the connecting region are those which are the strongest with respect to the main load of the fiber composite. The main load will in general be a tensile load, so that the layers which pass through will in general have a 0° fiber direction.

When oblique fiber directions are used, particularly with a 45° orientation, it is in each case expedient to allow a fiber layer with the $+\alpha$ orientation ($0° < \alpha < 90°$) to in each case rest directly against a fiber layer with the $-\alpha$ orientation, and to design this such that the two fiber layers together have the thickness of one 0° or 90° layer. This arrangement is also used to obtain a fiber composite

whose final form with respect to its center plane is as perfect as possible.

The composite material according to the invention is particularly suitable for high-strength connecting arrangements in an aircraft, for example for optimized coupling of stringers to a wing.

Ins C3 The invention will be explained in more detail in the following text with reference to exemplary embodiments which are illustrated in the drawing, in which:

Figure 1 - shows, schematically, a section through a composite material having a connecting region to produce a connection to an adjacent composite material of the same type,

Figure 2 - shows an aircraft wing with stringers composed of the composite material shown in Figure 1,

Figure 3 - shows an enlarged illustration of the transitional region between the fiber composite and the connecting region,

Figure 4 - shows a detailed, further enlarged illustration of the transitional region,

Figure 5 - shows a graphical representation to illustrate the tensile strength and embedding strength values of the materials used in the composite material,

Figure 6 - shows a graphical illustration of connection tensile strength values for the transitional region according to the invention, in comparison to two transitional regions of conventional design.

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Figure 1 shows a fiber composite 1 with numerous fiber layers 2 lying one on top of the other.

The fiber composite 1 merges via a transitional region 3 into a connecting region 4, in which fiber layers 2 which pass through the transitional region 3 alternate with metal layers 5 to form a fiber-metal laminate 6. The connecting region 4 of the composite material is bounded on both sides by lugs 7 in order to produce a connection to a connecting region 4 of a composite material that is fitted to form an extension, and these lugs 7 are likewise in the form of a fiber-metal laminate 6. In the connecting region 4, the composite material is connected to the lugs 7 by bolted joints 8. Since the lugs 7 extend continuously into the connecting region 4 of the adjacent composite material, and are likewise connected by bolted joints 8 to the connecting region 4 of the adjacent composite material, this results in a connection between the mutually adjacent composite materials via the lugs 7.

Figure 4 shows the construction of the transitional region 3 between the fiber composite 1 and the connecting region 4.

The fiber composite 1 is composed of fiber layers 2. The fiber composite 1 is in this case a 70/20/10 fiber composite. In consequence, 70% of it is formed with a 0° fiber direction, 20% with a +/- 45° orientation, and 10% with the 90° orientation.

The fiber layers 2 with the +45° and -45° orientations lie directly against one another and are each only half the layer thickness of the other fiber layers 2, so that, together, they form a fiber layer 2 with the same layer thickness as the other fiber layers 2.

Figure 4 shows that every alternate fiber layer 2 in the fiber composite 1 is in each case a 0° layer, and is constructed such that it passes through the transitional region 3 into the connecting region 4. In the connecting region 4, the intermediate spaces located between the 0° fiber layers 2 are filled by layers 9 composed of a reinforcement material, in this case a titanium alloy, so that the regular fiber-metal laminate 6 is formed in the connecting region 4.

The layers 9 composed of the reinforcement material extend for different extents into the transitional region 3 in the direction of the fiber composite 1, where they form abutment points 10 with fiber layers 2 which do not pass through. The abutment points 10 are not all arranged at the same level in the longitudinal direction, but are stepped.

Starting from the fiber composite 1, the two 90° fiber layers 2 end first of all, and form first

abutment points 10.

This is followed by two abutment points 10 of the +45°/-45° fiber layers 2, which form two further abutment points 10 at the same height.

The two other +45/-45° fiber layers, which are further outward, form a third height of abutment points 10. This is followed, at a distance, by two abutment points 10 between two 0° fiber layers 2 and the layers 9 composed of the reinforcement material, and at a further distance by two further abutment points 10.

The fiber layers 2 are arranged such that one 0° fiber layer 2 forms a center plane 11 of the composite material. In order to allow the desired 70/20/10 composition to be achieved for a predetermined thickness of the fiber composite 1 while maintaining the symmetry, the two fiber layers 2 on the surface (at the edge) are formed by 0° layers of half the thickness.

Figure 5 shows, in comparison, values for the tensile strength and the embedding strength of pure titanium layers 9, of the fiber composite 1 composed of CFC 70/20/10, and of the construction of the connecting region 4 according to the invention with 0° fiber layers 2 (CFC UD) and titanium layers 9, in the configuration shown in Figure 4.

The embedding strength of the normally used titanium alloys is the greatest, and that for the pure fiber composite 1 would be extremely low, so that it would not sensibly be possible to form a bolted joint 8

with the pure fiber composite 1. In contrast, the fiber composite 1 has a high tensile strength, which is considerably higher than the tensile strength of the titanium alloy. The fiber-metal laminate 6 in the connecting region 4 has an embedding strength which is only slightly less than the embedding strength of the titanium alloy, while the tensile strength of the laminate 6 is of virtually the same magnitude as that of the pure fiber composite 1.

The connecting region 4 designed according to the invention thus satisfies the requirements for a high tensile strength and a high embedding strength.

With regard to this result, it is still necessary to investigate whether the high tensile strength of the fiber composite 1 and of the connecting region 4 is also maintained over the transitional region 3.

Figure 6 shows that, as expected, a somewhat reduced tensile strength is achieved in the transitional region 3 designed according to the invention. However, in terms of the order of magnitude, this is in the region of the tensile strength of the fiber composite 1 and of the connecting region 4.

However, this does not apply to conventional solutions.

Figure 6 shows a transitional region 103 in which, according to a known solution, a monolithic titanium sheet 110 is provided with a stepped end, to which fiber layers 102 are connected in a stepped

manner. The connection tensile strength of this solution is less than half as great as that of the transitional region 3 according to the invention.

Another known solution sketched in Figure 6 provides a fiber composite composed of boron fiber layers 102, which form abutment points with steel sheets 109. The steel sheets 109 are connected to one another by adhesive layers 111. The connection tensile strength of such a transitional region 113 is, as is shown in the graphical illustration, somewhat higher than in the transitional region 103, but is only about 60% of the connection strength of the transitional region 3 according to the invention.

The composite material according to the invention thus combines high tensile strength values, even in the transitional region 3, with high embedding strengths in the connecting region 4.